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Effects of meteorological factors and the lunar cycle on onset of parturition in cows

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ABSTRACT

The present paper summarizes a comprehensive retrospective study that was undertaken to investigate effects of meteorological factors and lunar cycle on gestation length and daily birth rate in cows. To this end, all cattle births in Switzerland between 2008 and 2010 (n = 2,091,159) were related to detailed matched weather recordings. The study revealed some statistically significant effects of climate (temperature, barometric pressure, relative humidity) and weather (thunderstorms, heat index) on gestational length. Thunderstorms on the day before birth reduced the gestation length by 0.5 days. An increase in the birth rate was correlated with the temperature on the day before birth and the barometric pressure 3 days before birth. Differences in the barometric pressure >15 h Pa increased the birth rate by 4%. Nevertheless, the effects were not consistent and the modeled size of effect was so small that a clinical implication is unlikely. Although the daily birth rate was unevenly distributed across the lunar cycle, no clear pattern could be identified. Compared to the mean birth rate across the lunar cycle the highest daily birth rate was detected on day 4 after new moon (+1.9%) and the lowest on day 20 (−2.1%).

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1. Introduction

Parturition in cows is a complex and multifactorial process and many facets remain unknown despite extensive research in this field. Maternal and fetal endocrine functions in relation to parturition have been largely clarified; maturation of the fetal hypothalamo–hypophyseal–adrenal axis leads to secretion of fetal cortisol, which in turn causes increased estrogen production in the feto-placental unit. This increase results in maternal secretion of prostaglandin F2α (PGF2α) causing luteolysis and myometrial contractions, culminating in the birth of the calf (Noakes et al., 2009).

There are several endogenous and exogenous factors that are associated with onset of parturition and gestation length. The former include breed, fetal sex, and birth weight. In a study by Bleul (2008) mean gestation length differed by up to 9.5 days among cattle breeds with Jersey cows having the shortest and Blonde d'Aquitaine cows the longest gestation. In that study, the gestation length of heifer calves was 1.78 days shorter than that of bull calves. This phenomenon may be explained by a positive correlation between birth weight and gestation length (Gregory et al., 1991; Echternkamp and Gregory, 1999) because newborn heifer calves weighed up to 5% less than bull calves (Bleul, 2008).

Exogenous factors include season; calves born in the spring have a longer gestation length than calves born in the other seasons (Echternkamp et al., 2007; Bleul, 2008). Barometric conditions and the lunar cycle are other exogenous factors related to onset of parturition that are frequent topics of controversial debates, but relevant scientific veterinary studies are rare (Dvorak, 1978; Dickie et al., 1994). A study spanning several years and involving several hundred beef cows showed that parturition followed a mean decline in barometric pressure (Dvorak, 1978). On the other hand, a prolonged period of stable barometric conditions led to a reduction in gestation length of up to 5 days in cows of the Austrian Braunvieh breed (Dickie et al., 1994). There have been two studies in people that showed associations between clustering of births and pronounced barometric pressure changes or low barometric pressure (King et al., 1997; Akutagawa et al., 2007) but similar associations did not occur in other studies (Noller et al., 1996b; Morton-Pradhan et al., 2005). The effect of the lunar cycle on onset of parturition is even more controversial and, to our knowledge, there have been no veterinary studies on this topic. Studies of the lunar cycle and parturition in people have produced ambiguous results; most authors

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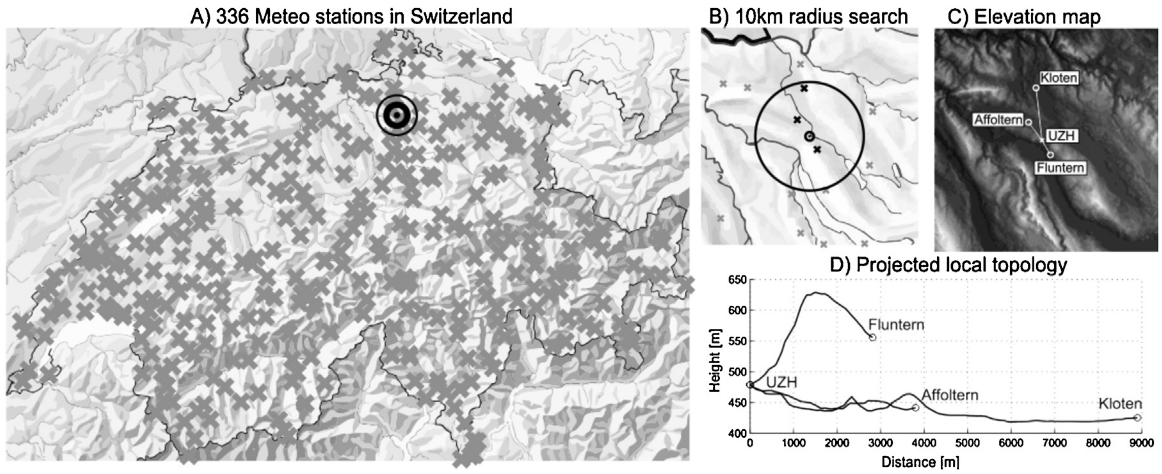

Fig. 1. Linking weather to individual births. (A) Map of Switzerland showing the location of all weather stations (grey crosses). (B–D) Identification of the weather station best suited for a particular birthplace (UZH): (B) Weather station must be within a 10-km radius of the birthplace (UZH). (C) Air lines between place of birth (UHZ) and 3 weather stations on grayscale terrain map based on Swisstopo digital height model with a 200 m grid (http://www.toposhop.admin.ch/de/shop/products/height/dhm25200_1). (D) Graphic representation of the computer-generated straight line that is contoured to the terrain between birthplace (UHZ) and 3 weather stations. These lines are used to calculate the topographic quotient *q*.

found no correlation between lunar phase and number of births (Arliss et al., 2005; Morton-Pradhan et al., 2005; Kuss and Kuehn, 2008; Staboulidou et al., 2008) while one found a trend (Menaker, 1967) and others a significant association between lunar phase and onset of labor (Ghiandoni et al., 1998).

The goal of this study was to investigate associations between multiple weather variables and lunar cycle and onset of parturition in cows. Since variables such as herd management and local climatic conditions are known to have an effect, the present study includes the entire cattle population of Switzerland over a 3-year period. Furthermore, data were analyzed in two ways: The first approach examined the effect of the weather preceding the individual birth on the gestation length, and the second approach examined whether and how meteorological factors and the lunar cycle affect the daily birth rate. Based on previous studies, our calculations focused on weather changes including fluctuations in barometric pressure, air temperature, and relative humidity, exceptional meteorological events such as thunderstorms, and on a high heat index. The latter has a profound effect on the well-being of people and animals (Dreiling et al., 1991; Dreschel and Granger, 2005).

2. Materials and methods

2.1. Animals

By law, all cattle in Switzerland have to be registered in a central database (http://www.tierverkehr.ch/). For the present study, data from all cattle born between January 1, 2008 and December 31, 2010 were extracted ($n = 2{,}157{,}055$). The data set contained breed, date of birth, farm registration number, and postal code of the birthplace. Date of conception is available for cattle registered in a breed association. Only those breeds and cross breeds that had at least 1000 births during the study period were included. The following criteria were enforced omitting potential errors of the extracted data: gestation length of 260–330 days, age of dam of 15 months to 26 years, and birth weight of 10–100 kg. Incomplete data sets were removed from the dataset, which left 2,091,159 births for analysis.

To minimize selection bias caused by breed occurrence or seasonal clustering of births, the gestation length and the birth rate (BR = number of births per day) were standardized (Bleul, 2008).

To account for breed–specific gestation length, the residual of gestation length was computed from the difference between breed average of the available dataset and the individual gestation length (residual of gestation length, RGL).

The seasonal variation of the birth rate attributable to seasonal alpine pasturing was accounted for by using a moving average birth rate at day i BR_i over a window of ±15 days ($N_\mathrm{F} = 15$):

$$\widehat{\mathrm{BR}}_i = \frac{1}{2N_\mathrm{F}+1}\sum_{j=i-N_\mathrm{F}}^{i+N_\mathrm{F}} \mathrm{BR}_j. \tag{1}$$

Finally, this running mean birth rate was subtracted from the observed birth rate to obtain the seasonally filtered variation of the birth rate, referred to as season independent birth rate (SIBR):

$$\mathrm{SIBR}_i = \mathrm{BR}_i - \widehat{\mathrm{BR}}_i + \frac{1}{N}\sum_{j=1}^{N}\mathrm{BR}_j. \tag{2}$$

2.2. Meteorological data

Meteorological data were retrieved from the Swiss federal meteorological database, MeteoSchweiz (IDAweb: http://www.meteoschweiz.admin.ch/web/de/services/datenportal/idaweb.html). Daily recorded variables from 336 Swiss weather stations were used (Fig. 1A). The following variables were selected because they are main determinants of weather and have the potential to affect the wellbeing of people and animals (Dreiling et al., 1991): maximum, minimum and mean barometric pressure corrected to sea level (p, h Pa), air temperature (T, °C), and relative humidity (φ, %); the latter two variables were measured 2 m above ground level. Days with thunderstorms in a 3 km radius of the birthplace were also considered because thunderstorms are a known stress factor (Dreschel and Granger, 2005).

The heat index (HI) was computed according to Rothfusz (Rothfusz, 1990) based on maximum and mean daily temperatures and relative humidity:

$$\begin{aligned}\mathrm{HI} &= c_1 + c_2T + c_3\varphi + c_4T\varphi + c_5T^2 + c_6\varphi^2 + c_7\mathrm{T}^2\varphi + c_8T\varphi^2 + c_9T^2\varphi^2\\ c_{1..9} &= [-8.79; 1.61; 2.34; -0.15; -1.23\times10^{-2}; -1.64\times10^{-2};\\ &\quad 2.21\times10^{-3}; 7.26\times10^{-4}; -3.58\times10^{-6}]\end{aligned} \tag{3}$$

The heat index describes how hot the weather is felt subjectively in °C. As the heat index depends on the thermal neutral zone of the species investigated, it was calculated for temperatures above 15 °C, which corresponds to the upper limit of the thermal neutral zone of cows (Bruce, 1986).

For the assessment of climatic effects on gestation length, weather data were attributed to individual births. A set of weather stations closest to each birthplace was preselected based on the geographical coordinates of the center of each postal code area (Fig. 1B). The geographical data were provided by the Swiss geographic information center, Swisstopo (http://www.swisstopo.admin.ch). As some stations did not have measurements for all weather variables, the stations were preselected for each variable independently. If no measurement was available within a 10-km radius, the variable was omitted in the data set. In a second step, local topographical features between birthplace and weather station (Fig. 1C) were considered, and a topography quotient q was computed as the ratio of the length of the profile line between the birthplace (Fig. 1D, e.g., UZH) and the weather stations (Fig. 1D, e.g., Fluntern/Kloten/Affoltern) and the air-line distance between the two locations according to:

$$q = \frac{\sum \sqrt{\Delta x_i^2 + \Delta y_i^2 + \Delta z_i^2}}{\sqrt{\Delta x^2 + \Delta y^2 + \Delta z^2}}, \tag{4}$$

where x is the latitude, y the longitude, z the elevation, and $\Delta x_i = \Delta y_i = 200$m the map resolution. A q-value close to 1 indicates little difference in elevation between the two locations and thus the likelihood of similar weather. Consequently, of the preselected weather stations, those with a q-value closest to 1 were selected.

Weather stations in extreme geographic regions and birthplaces higher than 1800 m above sea level were excluded because in these regions differences in weather conditions between close locations are common.

For the assessment of climatic effects on the daily birth rate, areas had to be identified that had homogeneous weather conditions and sufficient births to allow statistical analysis. According to MeteoSchweiz (personal communication Felix Blumer, MeteoSchweiz), barometric pressure and temperature are the variables with the most profound effects on weather conditions. In order to identify the weather station representing the largest area of Switzerland, the temperature and barometric pressure profiles of all stations with less than 700 m altitude were compared for the entire three-year study period, using

$$\Delta\bar{p}_{\mathrm{k,m}} = \frac{\sum_{i=1}^{N_{\mathrm{d}}} \left(p_{\mathrm{k}/i} - \bar{p}_{\mathrm{k}}\right) - \left(p_{\mathrm{m}/i} - \bar{p}_{\mathrm{m}}\right)}{N_{\mathrm{d}}}, \quad \Delta\bar{T}_{\mathrm{k,m}} = \frac{\sum_{i=1}^{N_{\mathrm{d}}} \left(T_{\mathrm{k}/i} - \bar{T}_{\mathrm{k}}\right) - \left(T_{\mathrm{m}/i} - \bar{T}_{\mathrm{m}}\right)}{N_{\mathrm{d}}}, \tag{5}$$

where $\overline{p_{\mathrm{k}}}$ is the mean barometric pressure at station k, $i \in [1, N_{\mathrm{d}}]$ is pressure $p_{\mathrm{k}\backslash i}$ at station k on day i for all days from January 1, 2008 to December 31, 2010 corresponding to a total of $N_{\mathrm{d}} = 1827$ days, and T is the analogous variables for temperature. Two weather stations k and m were considered similar if the mean differences of the daily temperature and the daily barometric pressure were smaller than $\Delta T_{\max} = 1$°C and $\Delta p_{\max} = 0.7$hPa, respectively. For each weather station ($\mathrm{k} \in [1, N_s]$, $N_s = 336$) the number of similar stations (n_{k}) was computed according to

$$n_{\mathrm{k}} = \sum_{m=1}^{N_s} \left(\overline{\Delta p}_{\mathrm{k},m} < \Delta p_{\max}\right) \tag{6}$$

To study the effect of climate on the birth rate, the population under investigation had to be subjected to similar weather conditions. The weather station that represented the largest number of cases was located in Wynau (white circle and cross in Fig. 2). Thus, for the analysis of climatic effects on the birth rate, all births that occurred within a 10 km radius of all stations similar to Wynau were considered (dark blue in Fig. 2). In the years 2008–2010, there were 859,027 (41% of all subjects) cattle births available for analysis in this area. This region, referred to as the Swiss Plateau, is bordered by the Alps in the south and represents an area with largely homogeneous climatic conditions (personal communication Felix Blumer, MeteoSchweiz).

2.3. Lunar data

Lunar data for the years 2008–2010 were retrieved from the NASA website (http://eclipse.gsfc.nasa.gov/phase/phase2001gmt.html). Each birth was assigned a value from 0.1 to 29.5 according to the period of time that had elapsed since the previous new moon. The value was rounded down to the next integer number, because the average lunar cycle length is 29.5 days and thus, the number of cows with a value of 29 days was smaller than for the other days. These cows were excluded from analysis to maintain equality in group size, which left 2,050,532 births for analysis.

2.4. Statistical analysis

The programs JMP9 (SAS Institute Inc., Cary NC, USA) and STATA 12 (Stata Corp., College Station, TX, USA) were used for statistical analysis. All analyses were done using multiple linear regression models with a stepwise backward elimination. The variables date of birth and farm registration number were included in the model as random effects. The area of Switzerland was divided in 9 regional clusters using the postal code of the birthplace (postal code 1000-1999, 2000-2999. . ..9000-9999). The 9 regions were included as dummy variables in the full model. Heteroskedasticity was tested according to the Breusch–Pagan/Cook–Weisberg test for each model. All p-values were >0.05, indicating no critical heteroskedasticity.

Due to the large sample size the level of significance was set at $p < 0.01$. The residual of gestation length and SIBR were normally distributed but the daily differences between maximum and minimum value of pressure (Δp), temperature (ΔT), and relative humidity ($\Delta\varphi$) on some of the test days were not. Hence, various transformations were tested to identify the ones that generated the best linearity. Square root (Δp on day 0; ΔT on day 0 and −3), inverse square root (Δp on day −10), and common logarithm transformations (Δp on day −1, −3 and −5 and ΔT on day −1 and −10) were used to normalize the input data.

2.4.1. Gestation length

To assess factors affecting residual gestation length (RGL), the following model was built:

$$\mathrm{RGL} = \sum_j \Delta p_j + \Delta T_j + \Delta\varphi_j + \Delta p_j \Delta T_j + \Delta p_j \Delta\varphi_j + \Delta T_j \Delta p_j + \Delta p_j \Delta T_j \Delta\varphi_j \tag{7}$$

where Δp_j is the difference between maximum and minimum barometric pressure, ΔT_j the difference between maximum and minimum temperature, and $\Delta\varphi_j$ the difference between maximum and minimum relative humidity on day j before parturition ($j \in [0, -1, -3, -5, -10]$), with day $j = 0$ corresponding to the day of birth. To capture all possible cofactor dependencies, calculations were carried out with all interaction terms, for instance $\Delta p_j \Delta T_j$. The data for days 0, −1, −3, −5, and −10 were also used to examine

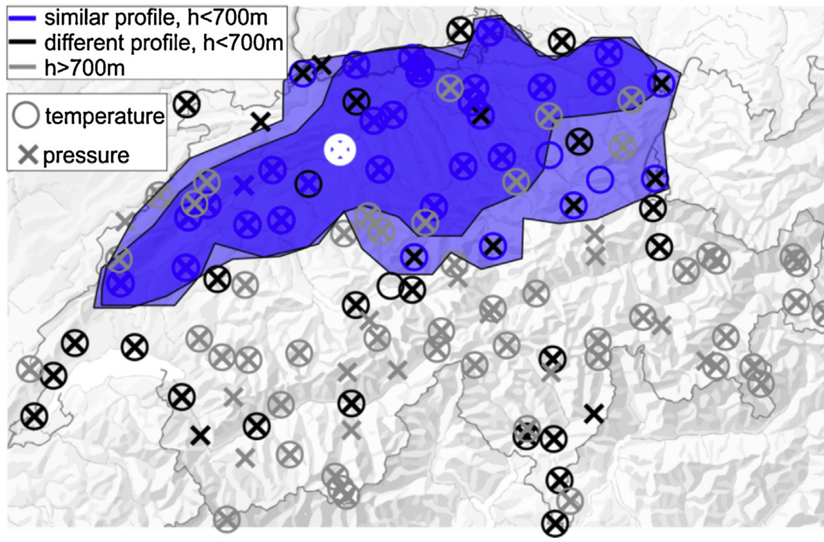

Fig. 2. Area with same weather conditions. Swiss weather stations with similar temperature (blue circles) and barometric pressure profiles (blue crosses), stations with dissimilar profiles (black crosses and circles) and stations higher than 700 m above sea level (grey circles and crosses). The region with a homogeneous temperature profile is shown in light blue and the region that also has a homogeneous barometric pressure profile is shown in dark blue. The weather station that is most representative of the area shown in dark blue is marked with a white circle and cross. (For interpretation of the references to color in this figure legend and text, the reader is referred to the web version of this article.)

the effect of the weather conditions that occurred before parturition.

To analyze the effect of relative changes in weather variables on gestation length, the RGL on days with a substantial rise or fall in barometric pressure ($p_{max} - p_{min} > 15$ h Pa) were compared with the RGL on days with minor fluctuations using a two-sample *t* test.

Furthermore, a linear regression model was used to identify correlations between RGL and the heat index (HI) on days *j* before parturition ($j \in [0, -1, -3, -5, -10]$) :

$$\mathrm{RGL} = \sum_{j} \Delta \mathrm{HI}_j \tag{8}$$

The effect of thunderstorms on RGL was tested by a linear regression model including the occurrence of thunderstorms (TS) on days *j* before parturition ($j \in [0, -1, -3, -5, -10]$):

$$\mathrm{RGL} = \sum_{j} \mathrm{TS}_j \tag{9}$$

2.4.2. Daily birth rate

To assess factors affecting the daily birth rate for cows on the Swiss Plateau, the following model was built for the season independent birth rate (SIBR):

$$\mathrm{SIBR} = \sum_{j} \Delta p_j + \Delta T_j + \Delta\varphi_j + \Delta p_j \Delta T_j + \Delta p_j \Delta\varphi_j + \Delta T_j \Delta p_j + \Delta p_j \Delta T_j \Delta\varphi_j \tag{10}$$

where Δp_j is the difference between maximum and minimum barometric pressure, ΔT_j the difference between maximum and minimum temperature, and $\Delta\varphi_j$ the difference between maximum and minimum relative humidity on day *j* before parturition ($j \in [0, -1, -3, -5, -10]$). Analogous to the analysis of the RGL, all possible cofactor dependencies were included and the data for days 0, −1, −3, −5, and −10 were used to examine the effect of the weather conditions that occurred before parturition.

To examine the effect of relative changes in weather variables on the birth rate, the SIBR on days with a marked rise or fall in barometric pressure ($p_{max} - p_{min} > 15$ h Pa) were compared with the SIBR on days with minor fluctuations using a two-sample *t* test.

2.4.3. The lunar cycle

The effect of the lunar cycle on onset of parturition was analyzed using a chi-square test, comparing the expected and the observed frequencies of being born on days 0–28 after a new moon. Because the lunar cycle is independent of season, the unstandardized birth rate (BR) was used for this. Additionally, a one-sample binomial test was used to examine whether the BR of a single test day differed significantly from the expected BR. The same calculations were also done for SIBR to ensure that seasonal changes did not mask the effect of the lunar cycle.

3. Results

3.1. Animals and farms

The 2,091,159 cows used in the study consisted of 26 breeds from 41,565 farms. The number of births per herd over the three-year-observation period was 50 ± 42 (range, 1–994 births) (Table 1).

3.2. Gestation length

The multiple linear regression model showed a significant correlation between RGL and Δp on the day of birth and the days d_{-0}, d_{-3}, d_{-5} and d_{-10}, between RGL and ΔT on d_0 and d_{-10}, between RGL and $\Delta\varphi$ on d_{-3} and d_{-5} and between RGL (Table 2). There was also a significant correlation between RGL and 7 of 9 regional clusters based on postal code of the birthplace. However the interaction between the regions and the weather variables showed full collinearity. Therefore die regional clusters were omitted from the model. There were no significant correlations between RGL and fluctuations in barometric pressure, temperature, and relative humidity at the day of birth and the days 0, −1, −3, −5, and −10 before parturition for any of the interaction terms.

Comparing days of birth with fluctuations of >15 h Pa with days of birth with minimal barometric pressure fluctuations, the RGL was 0.4 days longer ($p < 0.0001$).

The regression analysis between RGL and HI showed a significant decrease in RGL with increasing HI on days d_{-3}, $d_{-5,}$ and d_{-10} (Table 3).

Table 1
Distribution of cattle ($n = 2{,}091{,}159$) over breeds used in this study.

Breed	Number
Angus	41,358
Aubrac	3819
Blonde d'Aquitaine	4326
Braunvieh	481,430
Charolais	10,645
Dexter	3195
Eringer	19,017
Evolène	1018
Galloway	5787
Grauvieh	8158
Hereford	2335
Highland-Cattle	5808
Hinterwälder	2725
Holstein	235,156
Jersey	10,530
Cross-bred	429,680
Limousin	115,004
Montbéliard	27,046
Normande	3259
Piemontese	3305
Red Holstein	25,946
Rotfleckvieh	564,671
Salers	1757
Simmental	75,821
Swiss Fleckvieh	7650
Belgian Blue	1713

The regression analysis between RGL and thunderstorms showed a significant decrease in RGL with the occurrence of a thunderstorm on days d_0, d_{-1}, d_{-3}, d_{-5}, and d_{-10} (Table 4). Compared to days without thunderstorms, thunderstorm activity on the day of birth or in the days preceding parturition shortened RGL by 0.4–0.5 days.

3.3. Birth rate

There was a significant correlation between the SIBR and Δp on d_{-3} and ΔT on d_{-1} (Table 5). Furthermore, there were no significant correlations between SIBR and fluctuations in barometric pressure, temperature, and relative humidity on the day of birth and on days 0, −1, −3, −5, and −10 before parturition for any of the interaction terms.

The birth rate increased by a mean of 30 births on days with fluctuations of >15 h Pa compared with days with minimal barometric pressure fluctuations. This corresponded to an increase in the daily birth rate of 4% ($p < 0.001$, Fig. 3).

3.4. The lunar cycle

The expected probability of a birth occurring on any one of the 29 lunar days was 0.03448, which differed significantly from the observed likelihood in the effective birth rate (BR) as well as from the standardized number of births (SIBR, both $p < 0.0001$). Compared with the expected number of 70,662 births per day (BR), the maximum number of 71,987 births occurred on day 4 after a new moon and the minimum number of 69,211 births occurred on day 20. A period with a significantly lower BR between days 9 and 12 was followed by a period of a higher BR between days 13 and 15 (Fig. 4).

Table 2
Significant results of multiple linear regression with RGL (residual of gestation length) and Δp, ΔT, $\Delta\varphi$ on the days d_0, d_{-1}, d_{-3}, d_{-5}, and d_{-10} after stepwise backward elimination.

RGL	Coefficient	SEM	t	$p > t$	95% conf. interval	
Δp (d_0)	0.1801	0.0027	6.21	0.000	0.0127	0.0233
Δp (d_{-3})	0.0088	0.0027	3.25	0.001	0.0035	0.0141
Δp (d_{-5})	0.0125	0.0027	4.63	0.000	0.0072	0.0178
Δp (d_{-10})	0.0132	0.0027	4.93	0.000	0.0079	0.0184
$\Delta\varphi$ (d_{-3})	−0.0021	0.0007	−3.09	0.002	−0.0034	−0.0008
$\Delta\varphi$ (d_{-5})	−0.0023	0.0007	−3.44	0.001	−0.0037	−0.0011
ΔT (d_0)	−0.0073	0.0027	−2.75	0.006	−0.0125	−0.0020
ΔT (d_{-10})	−0.0173	0.0026	−6.58	0.000	−0.0225	−0.0122
–						
Intercept	0.4298	0.0727	5.91	0.000	0.2873	0.5723

Table 3
Significant results of multiple linear regression with RGL (residual of gestation length) and HI (heat index) on the days d_0, d_{-1}, d_{-3}, d_{-5}, and d_{-10} after stepwise backward elimination.

RGL	Coefficient	SEM	t	$p > t$	95% conf. interval	
HI (d_{-3})	−0.0081	0.0036	−2.26	0.024	−0.0151	−0.0011
HI (d_{-5})	−0.0084	0.0031	−2.68	0.007	−0.0146	−0.0023
HI (d_{-10})	−0.0364	0.0023	−16.11	0.000	−0.0408	−0.0319
Intercept	0.3757	0.0139	27.1	0.000	0.3485	0.4029

Table 4
Significant results of multiple linear regression with RGL (residual of gestation length) and thunderstorms on the days d_0, d_{-1}, d_{-3}, d_{-5}, and d_{-10} after stepwise backward elimination.

RGL	Coefficient	SEM	t	$p > t$	95% conf. interval	
TS (d_0)	−0.4398	0.0565	−7.78	0.000	−0.5506	−0.3291
TS (d_{-1})	−0.4036	0.0568	−7.11	0.000	−0.5149	−0.2922
TS (d_{-3})	−0.4653	0.0557	−8.35	0.000	−0.5744	−0.3561
TS (d_{-5})	−0.3731	0.0562	−6.64	0.000	−0.4831	−0.2630
TS (d_{-10})	−0.5332	0.0552	−9.65	0.000	−0.6415	−0.4250
Intercept	−0.0060	0.0103	−0.58	0.560	−0.0261	0.0142

Table 5
Significant results of multiple linear regression with SIBR (season independent birth rate) and Δp, ΔT, $\Delta\varphi$ on days d_0, d_{-1}, d_{-3}, d_{-5}, and d_{-10} after stepwise backward elimination.

SIBR	Coefficient	SEM	t	$p>t$	95% conf. interval	
Δp (d_{-3})	7.2004	2.6646	2.70	0.007	1.9722	12.4289
ΔT (d_{-1})	6.4376	2.0629	3.12	0.002	2.3900	10.4852
Intercept	753.8923	7.9472	94.86	0.000	738.2988	769.4857

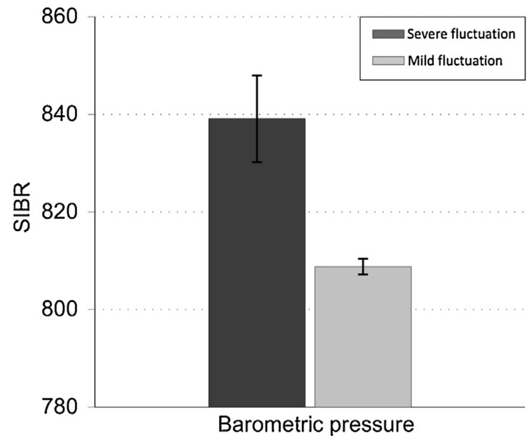

Fig. 3. Season independent birth rate (SIBR, mean ± SEM) on days with servere (>15 h Pa) and mild fluctuations in barometric pressure.

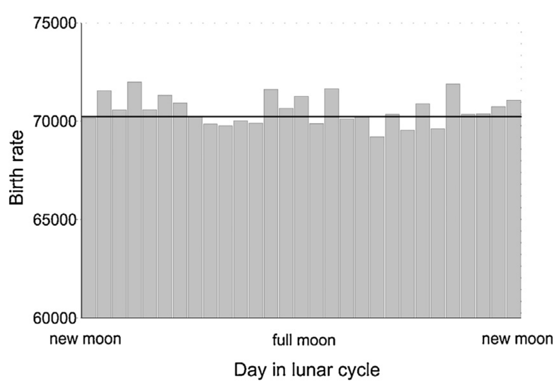

Fig. 4. Birth rate during the 29-day lunar cycle. The horizontal line marks the expected number of 70,662 births per day.

4. Discussion

Many factors can influence the onset of birth. Most of the known factors are local and affect a single herd or group of animals. At the herd level, management is a major contributing factor. The effect of individual herd management could be neglected in the present study because data from a large area were used and the herd size is very small in Switzerland. The mean number of births per herd over the 3-year observation period was 50 ± 42 ($x-$ ± SD), reflecting the small influence of single herds in relation to the total data set with 2,091,159 observed births. Furthermore farm registration number and the date of birth, which may be affected by the accuracy of recording the date (Robinson and Christley, 2006), could be eliminated from the final RGL model due to non-significance. The effects of global factors including the weather and lunar cycle on the onset of birth in mammals are frequently mentioned anecdotally but are not well defined in the present study.

Table 6
Summary of effects of weather fluctuations on SIBR (season independent birth rate) and RGL (residual of gestation length).

	Δp	ΔT	$\Delta\varphi$
Residuals of gestation length (RGL)	↑	↓	↓
Season independent birth rate (SIBR)	↑	↑	X

4.1. *Influence of barometric pressure, temperature, and relative humidity*

The influence of weather on the onset of parturition was investigated using two different surrogates, i.e., normalized gestation length (RGL) and birth rate (SIBR).

In general terms, pressure fluctuations (Δp) increased the RGL and SIBR, whereas temperature fluctuations (ΔT) decreased the RGL and increased SIBR. Humidity ($\Delta\varphi$) affected the RGL but not the SIBR (Table 6). The interpretation of these results is not straightforward. Fluctuations in barometric pressure and temperature are weather variables that generally are closely linked to each other and therefore could be expected to have similar effects on gestation length (personal communication, Felix Blumer, MeteoSchweiz); however, they had opposite effects on RGL. The effects of barometric pressure and temperature on SIBR were more consistent. However, when a statistical significance level of 5% (instead of 1%) was chosen, temperature fluctuations 3 days before parturition were negatively correlated with the SIBR. This discrepancy was caused by complex non-linear interactions between the 3 climate variables, which resulted in random significances when they were all included in a generalized linear model.

Other authors also were not able to detect a consistent effect of climatic factors on the onset of parturition. A survey involving 672 cows from a single herd showed that onset of parturition was associated with a significant fall in barometric pressure during the preceding 3 days. Although the mean pressure fell by 0.9 h Pa, it rose again by 0.5 h Pa during the last day before parturition (Dvorak, 1978). No association between barometric pressure and onset of parturition was detected in two studies involving human births occurring in two different hospitals (Noller et al., 1996a; Morton-Pradhan et al., 2005), but in another, 19% more births occurred on days when the barometric pressure was below the average of the preceding 8 years compared with days with average or increased barometric pressure (Akutagawa et al., 2007). In the same study, significantly greater barometric pressure fluctuations occurred on days with 2 or more births than on days with one or no births. Similarly, more births occurred within 24 h after a fall in barometric pressure than within 24 h before a fall in pressure (King et al., 1997). All these studies were based on the assumption that barometric pressure is the predominant factor, which is in agreement with the meteorological viewpoint that temperature and humidity act as co-factors to barometric pressure (personal communication, Felix Blumer, MeteoSchweiz). Numerous studies have shown that barometric pressure affects living organisms. In human medicine, barometric pressure and other weather conditions were observed to influence migraine and rheumatic pain. Frequency of migraine pain was significantly greater when the barometric pressure fell by more than 5 h Pa on the following day (Kimoto et al., 2011). Women with osteoarthritis of the hands had higher pain on days of rising barometric pressure than on days of falling or constant pressure (Wilder et al., 2003).

Laboratory rats and guinea pigs had more frequent signs of pain at low barometric pressure than at high pressure after iatrogenic ligation of the 5th lumbar spinal nerve (Sato et al., 2011). However, these pressure-related differences disappeared after destruction of the inner ear. The authors hypothesized that a pressure gradient between the atmosphere and the inner ear activates vestibular nuclei, which transmit signals to the hypothalamus, the part of the brain involved in pain processing. In the rat, there is morphological evidence of the existence of a pathway from the vestibular nuclei of the inner ear to the hypothalamus (Markia et al., 2008). Thus, an effect of barometric pressure on the birth process appears plausible. It is conceivable that barometric pressure-related nervous stimuli reaching the hypothalamus affect the prepartum period and onset of parturition because hypothalamic hormones are involved in initiation of parturition (Noakes et al., 2009). It was therefore reasonable to hypothesize that birth in cattle is affected by changes in meteorological variables, particularly barometric pressure. Although gestation length and daily birth rate are closely related to each other, the results for these two dependent variables often were contradictory in spite of the high significance level. The large sample size in the present study may have resulted in statistical significance of even very small differences, which may not detectable in a further model. Significant differences based primarily on large sample sizes must be interpreted carefully and may not be biologically relevant (Björklund and Bergek, 2009). For instance, a change in barometric pressure of as little as 0.14 h Pa on the day of birth had a significant effect on gestation length, whereas a massive change in barometric pressure of 15 h Pa increased RGL and SIBR by only 0.4 days and 4%, respectively, in the present study. Small changes of this magnitude are irrelevant and can be neglected when monitoring close-up cows for parturition because other factors such as breed and season have a more pronounced effect on onset of birth (Bleul, 2008). Furthermore, herd-specific management factors can affect the time of birth; for instance, the number of daytime births can be increased and the birth rate at night reduced by controlling the lighting regime and feeding times (Evans and Hacker, 1989; Gleeson et al., 2007).

4.2. Influence of heat index

Because heat index (HI) is a proxy for the subjectively felt temperature rather than a physical measurement, it is more reliable to assess biological effects. It has been established as a stressor in cattle (Sunil Kumar et al., 2011). The regression model indicated that a high HI on the days before parturition led to a shortened RGL. The maximum reduction in RGL by 0.7 ± 0.06 was observed when a high HI occurred 10 days prepartum. However, although statistically significant, this effect was marginal and hardly of clinical relevance. In contrast, a similar but much larger effect was identified in a study in humans. Gestation length of women dropped by up to 5 days when an extreme HI occurred on the day before birth (Dadvand et al., 2011). The authors compared this phenomenon with observations made in sheep and cattle. Sheep experimentally heat-stressed by exposure to a temperature of 48 °C for 75 min had a 60% increase in serum oxytocin concentration (Dreiling et al., 1991). Endometrial cell cultures from pregnant cows generated 20 times more $PGF_{2\alpha}$ at 43 °C compared with an incubation temperature of 39 °C (Putney et al., 1988). Oxytocin causes release of $PGF_{2\alpha}$ in vitro in endometrial cell cultures from pregnant cows as well as in vivo in pregnant cows (Putney et al., 1989). The release of $PGF_{2\alpha}$ is more pronounced in heat-stressed cell cultures and heat-stressed pregnant cows than in non-heat-stressed cell cultures and cows; however, the $PGF_{2\alpha}$ release was less pronounced in pregnant cows than in open cows (Putney et al., 1989). This led to the conclusion that the bovine fetus extenuates the oxytocin-induced release of $PGF_{2\alpha}$, but that the extenuation is affected by heat stress (Wolfenson et al., 1993).

Heat shock protein 70 is up-regulated by heat stress and is believed to have an effect on onset of parturition in women (Daugaard et al., 2007). Proteins of the heat shock 70 family have been associated with premature rupture of the membranes and premature delivery and thus with premature babies (Fukushima et al., 2005). Heat shock protein 70 was synthesized in increased amounts by heat-stressed cultures of endometrial cells from pregnant cows (Putney et al., 1988), but it is not known whether it has an effect on onset of parturition in this species. The association between heat index and onset of parturition could be a reason why the mean gestation length in the summer is shorter than in other seasons (Bleul, 2008).

4.3. Influence of thunderstorms

We observed that the RGL was shortened by about 0.4 days when a thunderstorm occurred during any of the last few days of gestation. This reduction may be explained by increased cortisol concentration in the pregnant cows after a thunderstorm, but it is too small to have a direct effect on herd management. A thunderstorm can be a stressful event for a cow and therefore cause increased cortisol secretion (Hollenstein et al., 2006; Bristow and Holmes, 2007). Likewise, some dogs reacted to thunderstorms with a massive increase (mean 207%) in cortisol secretion (Dreschel and Granger, 2005). Thunderstorms are often accompanied by changes in barometric pressure and could therefore have an indirect effect on the onset of parturition.

4.4. Influence of lunar cycle

In agreement with studies in women (Ghiandoni et al., 1998), calvings in the present study were not evenly distributed across the lunar cycle; there were a few days with a lower BR before and a few days with higher BR during full moon. To our knowledge, there have been no scientific explanations for the association between lunar cycle and onset of parturition. The gravitational force of the moon has been speculated to affect people as well as animals (Ghiandoni et al., 1998). In another study, the effect of the light emitted by the moon on the melatonin level and reproductive cycle in women was investigated (Law, 1986); 28% of the women examined started their menstrual cycle during a four-day period that was centered at the occurrence of a new moon, which differed significantly from the frequencies at other stages of the lunar cycle. Furthermore, at the start of their menstrual cycle, these women had significantly higher melatonin levels than at the time of ovulation. More research is needed to clarify the role of the lunar cycle in onset of parturition in cows.

5. Conclusion

An effect of climatic factors on the onset of parturition has often been postulated but could not be confirmed in this study. Although several highly significant correlations between various atmospheric variables and onset of parturition and daily birth rate were calculated, the findings were contradictory and not biologically/clinically relevant. Moreover, the effects of weather variables on the time of birth were small and likely to be masked by other factors both on an individual-cow and herd level.

Conflict of interest

The authors declare that they have no competing interests.

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